3.1.2.2 Acquisition Testing:

In addition to the continued accuracy testing, Phase II covered initial GPS acquisition testing in the presence of UWB. Using the same test configuration from Figure 3.3, the GPS aviation receiver was replaced with a high-end, general-purpose GPS receiver. The test procedure was as follows: the GPS signal at a fixed power level of –131.3 dBm was introduced into the receiver with specific levels of noise and UWB; the receiver was given one minute to acquire the signal; if the signal was acquired, the C/No was recorded. This test was repeated five times at each combined noise/UWB power level to provide multiple trials for each power point. Based on this test procedure, a noise calibration curve was generated, similar to what was done for PR accuracy. The maximum noise power at which the receiver was able to acquire the signal in all five trials was determined to be a baseline level. From this point, the broadband noise power was reduced by 4 dB and UWB was introduced in the band of increasing power levels until GPS acquisition failed over all 5 trials. This testing allows characterization of GPS acquisition in the presence of UWB relative to broadband noise. Results of this testing are presented in Figure 3.10.

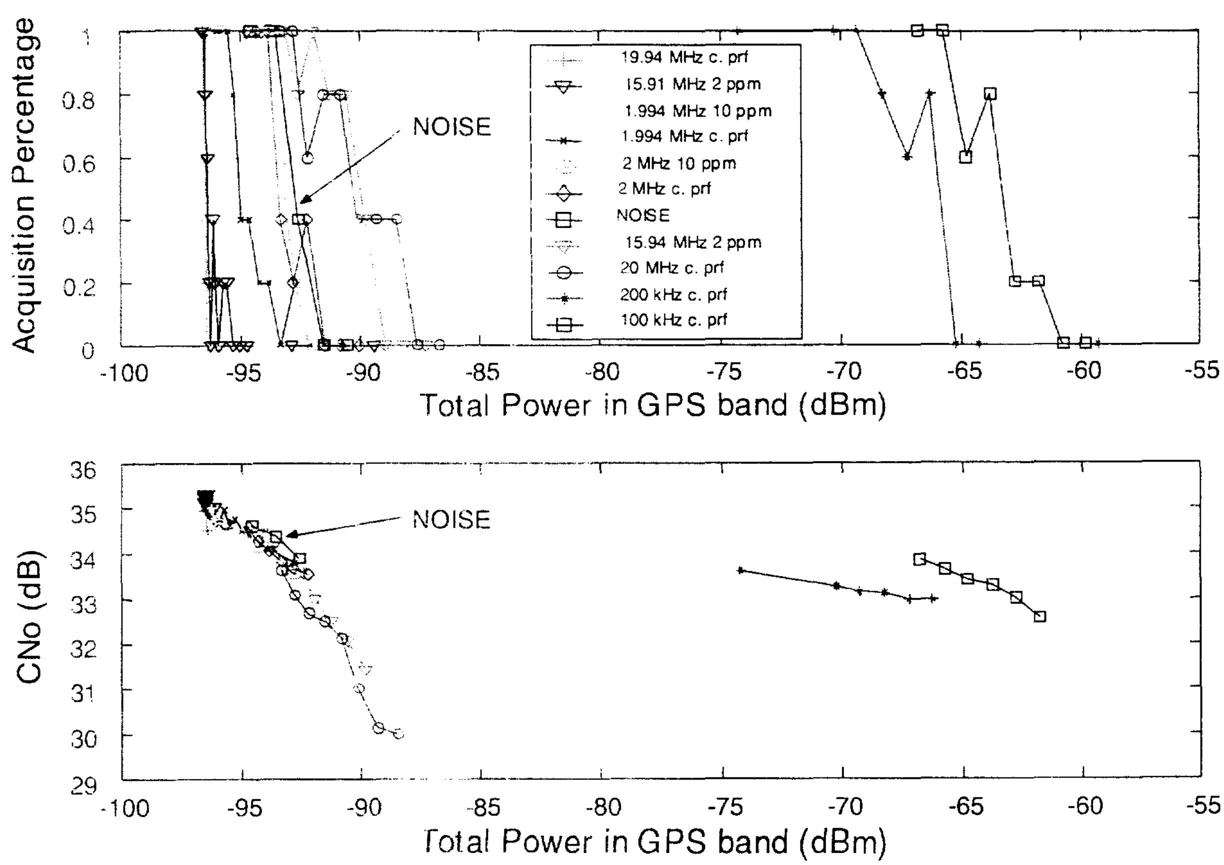

Figure 3.10. Result of GPS Acquisition Testing in the Presence of UWB/Noise

3.1.2.3 Stanford Results Summary:

Continued testing at Stanford University indicates that UWB has an adverse impact on the performance of GPS receivers and such performance is heavily dependent on UWB parameters. The most significant of such are the UWB pulse train modulation and resulting distinct spectrum lines.

The most problematic cases for accuracy testing (19.94 MHz constant PRF and 15.91 MHz 2 Position – Pulse Position Modulation (PPM)) are also the most problematic cases for GPS acquisition. The best case for GPS PR accuracy, that of UWB at a low PRF, was also the best case for the minimal impact of GPS acquisition performance.

Tabulated threshold-crossing power results at two specific broadband noise back-off points for a number of UWB waveforms of interest have been used to determine broadband noise equivalency factors for later use in RFI link budgets.

3.1.3 GPS Receiver UWB RFI Effects Model and Generalized RFI Analysis Equations

Appendix A provides some insight from an analytical perspective into how UWB RFI affects GPS receivers. This insight basically validates the test results obtained by Stanford University. It also validates the use of the large negative noise equivalency factor that is the difference between the application of discrete CW and random noise interference to the GPS receiver. Appendix B describes four general-purpose equations that cover the full range of RFI cases and demonstrate the sensitivity of GPS RFI response to UWB modulation format. Application of the Appendix B methodology makes it possible to extend the results for the tested receivers to other receiver cases with basic parameters in between the tested values.

3.2 Time Domain Corp.- Sponsored RFI Testing and Analysis

3.2.1 Applied Research Labs: University of Texas (ARL:UT) UWB RFI Data Collection Effort

As noted below, all conducted and radiated UWB RFI testing at ARL:UT has been completed and raw data have been posted on their web site. RTCA has received brief summaries of the actual procedures used and samples of the raw data collected. As noted in its first interim UWB RFI report, RTCA believes that, because of the inherent experimental problems in radiated RFI testing with live GPS signals, only the conducted RFI data is useful for further analysis. Also as noted in the first interim UWB report, however, no RFI analysis is possible without substantial data reduction. Johns Hopkins University Applied Physics Lab (JHU APL) has been contracted by Time Domain Corp. to perform that reduction (see 3.3.2 below). ARL:UT did not provide RTCA any detailed report text in suitable format that described their data collection campaign. They did, however, provide the following summary of their effort. The ARL:UT final report is available in part from their web site (noted below) and in total from the FCC electronic comment filing web site.[6]

The Applied Research Laboratories, The University of Texas at Austin (ARL:UT) has completed its measurement effort on the compatibility of Ultra Wideband (UWB) technologies and Global Positioning System (GPS) receivers. This measurement effort was not intended to produce an analytic result. Instead, it was intended to gather a data set that met the needs of the worldwide community and provide a public data set necessary for specific groups to make their own determination of impact. Over a four month period prior to testing, the test plan was presented to a large community that included members of public organizations such as the RTCA, academic organizations, and governmental organizations across the spectrum of governmental activity. Solicitations regarding improvements to the plan were sought and, where applicable and possible within the scope of the work effort, were implemented in order to acquire the most relevant data sets possible.

The test report describing the data collection effort has been produced and was submitted to the FCC on February 27, 2000 to be included as part of the comments on the FCC's NPRM. The data, and the test report, are public and available at the ARL:UT web site at http://sgl.arlut.utexas.edu/asd/Cure/testplan.html.

The testing involved a number of different GPS receivers (Novatel 3151; Ashtech Z12; Garmin International GPS 150 XL, Ashtech Z-Sensor; Novatel Millennium; and the Trimble 4700), several different UWB devices (Time Domain PAD, Time Domain signal generator, Sensors and Software Noggin 1000 GPR, Sensors and Software Noggin 250 GPR), as well as some existing digital devices (Motorola Radius SP10 Walkie-Talkie, and a Gateway Model GP7-450, Mini-Tower, Personal Computer) that have the potential to impact on GPS receivers. Over 10 Gigabytes of data has been acquired and, although the data set is large, the directory structure the data has been placed in lends itself readily to analysis by personnel familiar with the tools and methods necessary for analysis of GPS data. This fact has been proven by the numerous,

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[6] FCC ECFS web site, proceeding number 98-153

worldwide requests for information which ARL:UT has fielded from personnel actively analyzing the data.

3.2.2 Johns Hopkins University Applied Physics Laboratory (JHU/APL) Data Reduction and Analysis

On March 13, 2001, JHU/APL presented the RTCA the executive summary of their final report[7] and some supporting material to explain their ARL:UT RFI data analysis. The following text from the JHU/APL report executive summary has added comments by RTCA as noted that reflect points of contention raised in the meeting.

The Johns Hopkins University Applied Physics Laboratory (JHU/APL) has conducted a focused and independent assessment of the effects of ultra-wide band (UWB) emissions on GPS receiver performance. This assessment is based on a statistical evaluation of data collected by the Applied Research Laboratories University of Texas at Austin (ARL:UT) along with a strictly theoretical analysis. The ARL:UT data were gathered using six specific GPS receivers, two configurable UWB device types and four other devices currently regulated under FCC Part 15 rules.

The objective of this assessment was to quantify the relationship among key GPS performance parameters and UWB emissions parameters such that from this work policy makers can gauge the impact of potential UWB emissions. The results of this work are being provided to the FCC to assist them in making informed regulatory decisions with regard to UWB emissions under Part 15. Based on this assessment, JHU/APL has drawn the following conclusions.

1. UWB time coding or modulation implementation determines the nature of the resulting UWB signal. This nature in turn determines the impact on a particular GPS receiver implementation and its performance. The choices of time coding parameters can produce significant differences in the amount and type of performance effect experienced by GPS receivers.
2. The theoretical analysis and statistical data evaluation show that properly time coded UWB signals can be produced that have characteristics similar to white noise within the GPS frequency spectrum. White noise energy is uniformly distributed in frequency and will not excite any complex interactions in GPS receivers. The properties of white noise allow it to be characterized by average power when taken in the context of overall GPS receiver performance, and this performance is a well studied interaction. The UWB devices tested by ARL:UT produce signals that are white noise-like. The aggregate signal produced by more than one of these devices is also white noise-like.

RTCA disagrees with the characterization of "white noise-like" for the individual UWB devices tested. It appears from Joint Spectrum Center analysis of the same UT data set that these signals actually contain spectral lines spaced at PRF/1024 Hz. For example, a 5 MHz PRF yields a line spacing of 4.88 kHz. The effect on the receiver cycle slip rate appears to be associated with aligning of these 4.88 kHz lines with the C/A code spectral lines, thereby producing effects that are time varying and only weakly correlated with UWB interference power.

[7] JHU/APL Strategic Systems Department, "Final Report: UWB RFI Analysis Project," 8 March, 2001, available at the FCC ECFS web site, proceeding number 98-153

3. There exist coding schemes that can produce non-white noise-like UWB signals that may have a greater impact on GPS performance than those effects shown herein.

RTCA notes that other testing efforts have shown coding schemes that actually do produce non-white-noise-like effects. (see, for example, Section 3.1.2 of this RTCA report.) The JHU/ APL theoretical analysis (JHU/APL report Ch. 5) does predict such effects.

4. For UWB devices with average powers that are compliant with the current FCC Part 15 regulations, the performance of GPS receivers exhibits severe degradation when the separation between the GPS receiver and UWB devices is less than about 3 meters. This distance is based solely on the GPS receivers and UWB devices tested by ARL:UT. As the separation decreases below 3 meters, all users of these GPS receivers will be severely impacted, and in the extreme, lose lock on all satellites. This phenomenon is exhibited across all relevant measures of performance analyzed. The single Part 15 device that was analyzed induced similar behavior in the GPS receivers.

RTCA disagrees with the arbitrary selection of 3 meter separation for the onset of "severe degradation" for several reasons. (1) Report data[8] contradict the conclusion that 3 meters is an appropriate distance separation for GPS effects analysis. (2) An emitter at the Part 15 average power limit (-71.3 dB W/MHz) produces a signal into an isotropic antenna 3 meters away which is over 200 times the internationally accepted standard for unacceptable interference to the GPS receiver.[9] This is equivalent to a noise density that is 24.3 dB above the thermal noise density for a typical GPS receiver. (3) Improper factors were used in the conversion from attenuator setting to equivalent range. Examination by RTCA of the basic ARL:UT measurements suggests that the performance degradation actually takes place at power levels (and associated distances) consistent with the international standards (see also Sec. 3.1 and 3.4 of this RTCA report) (4) The introduction of a range relation implies that a scenario-dependent link budget was employed when, in fact, it was not. (5) The criteria used to define "severe degradation" were somewhat arbitrary and not consistent with international standards, and did not include any safety-of-life margins.

5. For separations greater than 3 meters, GPS receiver performance converges to nominal levels. The minimum separation at which degradations are acceptable depends on individual user scenarios including performance thresholds, GPS receiver and UWB device(s).

RTCA notes that the 3 meter value is unrealistic (see RTCA comment above). Also, there is no explanation of "nominal levels."

6. Variations in the measures of performance due to different GPS receivers are greater than those due to the operating modes of the UWB tested devices. The impact of UWB devices on all GPS receivers cannot be assessed using a single GPS receiver.

RTCA notes that the measures of performance are inadequate for many GPS applications. For example, cycle slip occurrence, not chosen as a MOP, is a critical measure for survey receiver performance, and for aviation precision approach.

[8] See JHU/APL Final Report Chapter 6. Figures 6-4, -5, -6, -9, -11
[9] ITU-R M.1477

The JHU-APL report summary concludes with the statement, "The reader is encouraged to use the results presented in the remainder of this report to draw additional appropriate conclusions. Based on this report and the inputs from other organizations, JHU/APL believes that sufficient information is available for the FCC to establish criteria for regulating UWB emissions. Methodologies such as those presented in this report can be used to help the FCC evaluate the application of these criteria." RTCA believes that it is very inappropriate for JHU/APL to judge the sufficiency of the FCC record in the UWB proceeding. This final conclusion is inconsistent with and unsupported by the certain results in the body of their work as pointed out above. The conclusion is far too general and sweeping in relation to a study of only GPS L1 band RFI effects (See, for example, the discussion of the NTIA study in section 3.3 of this RTCA report).

3.3 NTIA Tests on Ultra-Wideband Devices and Compatibility with Non-GPS Federal Systems[10]

NTIA has conducted a series of measurements and analyses for characterizing and assessing the impact of UWB devices on selected Federal equipment operating between 400 and 6000 MHz, which includes 18 bands and a total of 2502.7 MHz of restricted spectrum.[11] The results include practical methods for characterizing UWB systems and providing the information needed to estimate or measure their potential to interfere with existing radio communications or sensing systems.[12]

NTIA calculated the maximum permissible, average Equivalent Isotropic Radiated Power (EIRP) density in a 1 MHz bandwidth (average EIRP, dBm/MHz (RMS)) that would allow a UWB device to transmit without exceeding the protection criterion determined for each of the systems analyzed after coordination with that system's users.[13] Throughout this section, the average power was calculated from the Root Mean Square (RMS) voltage of the UWB signal. For clarity and simplicity the average power has been written as average (RMS) power and the average spectral density expressed as dBm/MHz (RMS). In addition, NTIA calculated the minimum separation distance at which a UWB device with an average EIRP spectral density of -41.3 dBm/MHz (RMS), which is equivalent to the average field strength specified in Part 15 for devices operating above 1 GHz (a field strength of 500 μV/m at a 3 meter separation distance measured in a 1 MHz bandwidth), will ensure that the protection criteria are met in that receiver. Both the effects of one single UWB emitter on one receiver and of an aggregate of several UWB emitters on one receiver were analyzed. Throughout the assessment, the UWB devices analyzed were presumed to overlap the bands used by the equipment being assessed completely. The analytical results developed were been compared with the measurements made at NTIA's Institute for Telecommunication Sciences (ITS) in Boulder, Colorado and field measurements made at the Federal Aviation Administration facilities at Oklahoma City, Oklahoma.

The power levels of the UWB devices are expressed here as RMS spectral power densities, as noted above, rather than the average of the logarithms of the peak power densities measured with

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[10] Section 3.3 is an excerpt of the Executive Summary of NTIA Special Publication 01-43, "Assessment of Compatibility between Ultra-Wideband Devices and Selected Federal Systems," Jan., 2001.

[11] In addition, because of widespread concern, both the Interagency Government Executive Board, which oversees the development of the Global Positioning System (GPS), and the Federal Aviation Administration (FAA), have funded NTIA to conduct a related series of studies assessing UWB impact on GPS receivers. The measurements involving GPS receivers will be reported separately in a later document. See National Telecommunications and Information Administration, *Notice, Request for Comments on Global Positioning System/Ultrawideband Measurement Plan, 65 Fed. Reg. 49544 (Aug. 14, 2000).*

[12] NTIA and the Institute for Telecommunication Sciences with the support of the National Institute of Science and Technology verified the accuracy of the measurements made using readily available commercial test equipment in three separate ways. The first was by very accurately measuring the temporal (time domain) characteristics of the several devices and comparing the Fourier transformations of the signals in various bandwidths with measurements of the actual spectrums received in those bandwidths. The second was by theoretical analyses of the waveforms and their spectrums. The third way was through numerical simulations of the waveforms.

[13] The protection criteria, which are presented in Appendix A, are based on ITU-R Recommendations, ICAO Standards, and RTCA Minimum Operational Performance Criteria and were provided by the agencies operating the affected systems. NTIA's model is not generally accurate at ranges less than 200 meters due to uncertainties of near field, propagation and antenna gain.

the video averaging technique used by the FCC for measuring narrow band Part 15 devices. Although NTIA recognizes that no single average detector function adequately describes the interference effects of UWB signals, the RMS detector function better represents the interference effects of UWB signals than averages of the logarithms of the peak detector output of the video filtered response used by the FCC for Part 15 measurements.

3.3.1 Results: Single Emitter

TABLES 1 and 2 provide the results of NTIA's analyses of the effect of single UWB emitters on selected devices. TABLE 1 shows the results for all the systems analyzed, assuming that receiver performance degradation is a function of the UWB signal average power, while TABLE 2 shows the results of the analyses for digitally modulated Earth stations in which receiver performance degradation may be a function of the UWB signal peak power. In TABLE 2 the lower PRF rows are shaded to reflect a possible restriction of the ratio of permissible peak power in a 50 MHz band to the RMS power in a 1 MHz band to less than 30 dB.[14]

To better understand TABLE 1 please look at the results for the Terminal Doppler Weather Radar (TDWR), which shows that a UWB device with an EIRP in the 5600-5650 MHz band of -41.3 dBm/MHz (RMS) could operate out-of-doors without exceeding the TDWR's protection criteria at heights of 2 meters or less with no geographic restriction. Moreover, a UWB device at 2 meters would require an in-band EIRP of -35 dBm/MHz (RMS) or greater to exceed the TDWR's protection criteria. The entry for the Air Route Surveillance Radar (ARSR-4), however, shows that a UWB device at a height of 2 meters with an EIRP of -41.3 dBm/MHz (RMS) in the 1240-1370 MHz band would have to stay about 6 km away to meet the radar's protection criterion or reduce its in-band EIRP to about -61 dBm/MHz (RMS). Please note also that TABLE 1 shows also that if UWB devices were to operate in the same horizontal plane as the TDWR or ARSR-4 antennas (see the columns labeled UWB Ht = 30 m), then the separation distance would have to increase to 6 km for the TDWR and over 15 km for the ARSR-4, or the in-band EIRPs would have to decrease to -63 dBm/MHz (RMS) for the TDWR and -82 dBm/MHz (RMS) for the ARSR-4.

TABLE 1
Summary of Assessment of Effects of UWB Devices on Federal Systems
For Average Power Interactions[Note]

SYSTEM	Freq. (MHz)	UWB PRF (MHz)	UWB Height 2 Meters				UWB Height 30 Meters			
			Non-Dithered		Dithered		Non-Dithered		Dithered	
			Max. EIRP to Meet Protect. Criteria (dBm/MHz (RMS))	MinSep.(km) for -41.3 dBm/MHz (RMS) EIRP to Meet Protect. Criteria	Max. EIRP to Meet Protect. Criteria (dBm/MHz (RMS))	MinSep.(km) for -41.3 dBm/MHz (RMS) EIRP to Meet Protect. Criteria	Max. EIRP to Meet Protect. Criteria (dBm/MHz (RMS))	MinSep.(km) for -41.3 dBm/MHz (RMS) EIRP to Meet Protect. Criteria	Max. EIRP to Meet Protect. Criteria (dBm/MHz (RMS))	MinSep.(km) for -41.3 dBm/MHz (RMS) EIRP to Meet Protect. Criteria

[14] The 30 dB value was chosen for illustrative purposes and does not suggest an NTIA policy position. This 30 dB value would limit the PRF of UWB non-dithered devices to values greater than 3.5 MHz, and of UWB dithered devices to values greater than 12.5 MHz as shown in Appendix D.

TABLE 1

Summary of Assessment of Effects of UWB Devices on Federal Systems For Average Power Interactions[Note]

SYSTEM	Freq. (MHz)	UWB PRF (MHz)	UWB Height 2 Meters, Non-Dithered: Max. EIRP to Meet Protect. Criteria (dBm/MHz (RMS))	UWB Height 2 Meters, Non-Dithered: MinSep.(km) for -41.3 dBm/MHz (RMS) EIRP to Meet Protect. Criteria	UWB Height 2 Meters, Dithered: Max. EIRP to Meet Protect. Criteria (dBm/MHz (RMS))	UWB Height 2 Meters, Dithered: MinSep.(km) for -41.3 dBm/MHz (RMS) EIRP to Meet Protect. Criteria	UWB Height 30 Meters, Non-Dithered: Max. EIRP to Meet Protect. Criteria (dBm/MHz (RMS))	UWB Height 30 Meters, Non-Dithered: MinSep.(km) for -41.3 dBm/MHz (RMS) EIRP to Meet Protect. Criteria	UWB Height 30 Meters, Dithered: Max. EIRP to Meet Protect. Criteria (dBm/MHz (RMS))	UWB Height 30 Meters, Dithered: MinSep.(km) for -41.3 dBm/MHz (RMS) EIRP to Meet Protect. Criteria
Distance Measuring Equipment (DME) Interrogator Airborne Rcvr	960-1215	□0.1 □1	-46 -47	0.08 0.09	-46 -46	0.08 0.08				
DME Ground Transponder Rcvr	1025-1150	□0.1 □1	-63 -64	0.26 0.29	-63 -63	0.26 0.26	-56 -57	0.26 0.29	-56 -56	0.26 0.26
Air Traffic Control Radio Beacon Sys (ATCRBS) Air Transponder Rcvr	1030	□1 □10	-44 -37	0.02 NA	-44 -44	0.02 0.02				
ATCRBS Gnd Interrogator Rcvr	1090	□1 □10	-31 -21	NA NA	-31 -31	NA NA	-45 -36	0.27 NA	-45 -45	0.27 0.27
Air Route Surveil. Radar (ARSR-4)	1240-1370	□0.1 □0.1	-60 -61	5.5 6.1	-60 -60	5.5 5.5	-80 -82	>15 >15	-80 -80	>15 >15
Search & Rescue Sat. (SARSAT) Ground Station Land User Terminal (LUT)	1544-1545	□0.1 □1	-68 -69	2.9 3.1	-68 -68	2.9 2.9	-65 -66	5.5 6.1	-65 -65	5.5 5.5
Airport Surveillance Radar (ASR-9)	2700-2900	□0.1 □1	-44 -46	0.8 1.1	-44 -44	0.8 0.8	-64 -66	1.3 1.5	-65 -65	1.3 1.3
Next Gen Weather Radar (NEXRAD)	2700-2900	□0.1 □1	-39 -42	NA 1.4	-39 -39	NA NA	-73 -76	5.8 7.9	-73 -73	5.8 5.8
Maritime Radars	2900-3100	□1 □10	-56 -50	1.2 0.6	-56 -56	1.2 1.2	-57 -51	1.2 0.6	-57 -57	1.2 1.2
FSS Earth Station (20□ Elevation)	3700-4200	□1 10 □100	-36 -26 -20	NA NA NA	-36 -36 -36	NA NA NA	-42 -32 -26	.20 NA NA	-42 -42 -42	.20 .20 .20
FSS Earth Station (5□ Elevation)	3700-4200	□1 10 □100	-51 -41 -35	0.60 NA NA	-51 -51 -51	0.60 0.63 0.63	-77 -67 -61	1.0 0.6 0.4	-77 -77 -77	1.0 1.0 1.0

TABLE 1
Summary of Assessment of Effects of UWB Devices on Federal Systems For Average Power Interactions[Note]

SYSTEM	Freq. (MHz)	UWB PRF (MHz)	UWB Height 2 Meters — Non-Dithered: Max. EIRP to Meet Protect. Criteria (dBm/MHz (RMS))	UWB Height 2 Meters — Non-Dithered: MinSep.(km) for -41.3 dBm/M-Hz (RMS) EIRP to Meet Protect. Criteria	UWB Height 2 Meters — Dithered: Max. EIRP to Meet Protect. Criteria (dBm/MHz (RMS))	UWB Height 2 Meters — Dithered: MinSep.(km) for -41.3 dBm/M-Hz (RMS) EIRP to Meet Protect. Criteria	UWB Height 30 Meters — Non-Dithered: Max. EIRP to Meet Protect. Criteria (dBm/MHz (RMS))	UWB Height 30 Meters — Non-Dithered: MinSep.(km) for -41.3 dBm/M-Hz (RMS) EIRP to Meet Protect. Criteria	UWB Height 30 Meters — Dithered: Max. EIRP to Meet Protect. Criteria (dBm/MHz (RMS))	UWB Height 30 Meters — Dithered: MinSep.(km) for -41.3 dBm/M-Hz (RMS) EIRP to Meet Protect. Criteria
CW Radar Altimeters at minimum altitude	4200-4400	≤0.1	25	NA	25	NA				
		≥1	14	NA	14	NA				
Pulsed Radar Altimeters at Minimum Altitude	4200-4400	≤1	14	NA	14	NA				
		10	14	NA	14	NA				
		≥10	14	NA	14	NA				
Microwave Landing System	5030-5091	≤0.1	-45	0.07	-45	0.07				
		≥1	-54	0.16	-45	0.07				
Terminal Doppler Wx Radar (TDWR)	5600-5650	≤1	-35	NA	-35	NA	-63	6.0	-63	6.0
		≥10	-35	NA	-35	NA	-63	6.0	-63	6.0

Note (1) The calculations were made at UWB PRF Values of, 0.001, 0.01, 0.1, 1, 10, 100, and 500 MHz. When the distance values and Maximum EIRP values were the same for a range, they were grouped together to save space in the table. Thus, for the first row, the calculations for PRF values of 0.001, 0.01, and, 0.1 MHz were the same and are shown in the row labeled ≤0.1 MHz, while the calculations for 1, 10, 100, and 500 MHz were the same and are shown in the row labeled ≥1 MHz. (2) The shaded areas represent implausible scenarios where the UWB and aircraft would be at the same altitude (i.e., a collision course). (3) The symbol NA indicates that the maximum calculated EIRP never exceeded -41.3 dBm/MHz (RMS).

TABLE 2 shows that if the receiver performance degradation to digital Earth terminals is related to the peak power rather than the average power, separation distances or additional losses would have to increase to meet the protection criteria established for those receivers.

TABLE 2
Summary of Assessment of Effects of UWB Devices on Federal Systems For Peak Power Interactions with Digitally Modulated Systems[Note]

SYSTEM	Freq. (MHz)	UWB PRF (MHz)	UWB Height 2 Meters — Non-Dithered: Max. EIRP to Meet Protect. Criteria (dBm/MHz (RMS))	UWB Height 2 Meters — Non-Dithered: MinSep.(km) for -41.3 dBm/MHz (RMS) EIRP to Meet Protect. Criteria	UWB Height 2 Meters — Dithered: Max. EIRP to Meet Protect. Criteria (dBm/MHz (RMS))	UWB Height 2 Meters — Dithered: MinSep.(km) for -41.3 dBm/MHz (RMS) EIRP to Meet Protect. Criteria	UWB Height 30 Meters — Non-Dithered: Max. EIRP to Meet Protect. Criteria (dBm/MHz (RMS))	UWB Height 30 Meters — Non-Dithered: MinSep.(km) for -41.3 dBm/MHz (RMS) EIRP to Meet Protect. Criteria	UWB Height 30 Meters — Dithered: Max. EIRP to Meet Protect. Criteria (dBm/MHz (RMS))	UWB Height 30 Meters — Dithered: MinSep.(km) for -41.3 dBm/MHz (RMS) EIRP to Meet Protect. Criteria
Search & Rescue Sat. (SARSAT) Ground Station Land User Terminal (LUT)	1544-1545	0.001	-104	>15	-104	>15	-101	>15	-101	>15
		0.01	-94	12.0	-94	12.0	-91	>15	-91	>15
		0.1	-84	7.3	-84	7.3	-81	>15	-81	>15
		1	-74	4.2	-74	4.2	-71	11.3	-71	11.4

TABLE 2
Summary of Assessment of Effects of UWB Devices on Federal Systems For Peak Power Interactions with Digitally Modulated Systems[Note]

SYSTEM	Freq. (MHz)	UWB PRF (MHz)	UWB Height 2 Meters				UWB Height 30 Meters			
			Non-Dithered		Dithered		Non-Dithered		Dithered	
			Max. EIRP to Meet Protect. Criteria (dBm/MHz (RMS))	MinSep.(km) for -41.3 dBm/MHz (RMS) EIRP to Meet Protect. Criteria	Max. EIRP to Meet Protect. Criteria (dBm/MHz (RMS))	MinSep.(km) for -41.3 dBm/MHz (RMS) EIRP to Meet Protect. Criteria	Max. EIRP to Meet Protect. Criteria (dBm/MHz (RMS))	MinSep.(km) for -41.3 dBm/MHz (RMS) EIRP to Meet Protect. Criteria	Max. EIRP to Meet Protect. Criteria (dBm/MHz (RMS))	MinSep.(km) for -41.3 dBm/MHz (RMS) EIRP to Meet Protect. Criteria
		□10	-69	3.1	-68	2.9	-66	6.1	-65	5.4
		0.001 0.01 0.1 1	-89 -79 -69 -59	6.6 3.9 2.2 1.2	-89 -79 -69 -59	6.6 3.9 2.2 1.2	-95 -85 -75 -65	>15 >15 5.3 1.7	-95 -85 -75 -65	>15 >15 5.3 1.7
		10	-39	NA	-50	0.5	-45	0.25	-55	0.6
FSS Earth Station (20□ Elevation)	3700-4200	100	-20	NA	-40	NA	-26	NA	-45	0.25
		500	-20	NA	-36	NA	-26	NA	-42	.20
		0.001 0.01 0.1 1	-104 -94 -84 -74	12.3 8.4 5.1 3.0	-104 -94 -84 -74	13.2 8.4 5.1 3.0	-130 -120 -110 -100	>15 >15 >15 10.1	-130 -120 -110 -100	>15 >15 >15 10.2
		10	-54	1.0	-64	1.7	-80	1.3	-90	3.3
FSS Earth Station (5□ Elevation)	3700-4200	100	-35	NA	-54	1.0	-61	0.44	-80	1.3
		500	-35	NA	-51	0.6	-61	0.44	-77	1.0

Note: (1) The calculations were made at UWB PRF Values of, 0.001, 0.01, 0.1, 1, 10, 100, and 500 MHz. When the distance values and Maximum EIRP values were the same for a range, they were grouped together to save space in the table. Thus, for the LUT the calculations for 10, 100, and 500 MHz were the same and are shown in the row labeled □10 MHz. (2) The shaded areas are for PRF values that would result in peak-to-average power levels greater than 30 dB.

3.3.2 Results: Aggregate Emitters

NTIA examined the implications of possible aggregate interference from UWB devices and developed a number of findings, both general and specific. NTIA developed the UWBRings computer model for this study to calculate effectively aggregate interference levels in a given receiver under a variety of conditions. The model is based upon two fundamental assumptions – that the UWB emitters are uniformly distributed geographically and that the average power received from each emitter adds linearly.

NTIA validated both the aggregate interference assumptions and the methodology through two steps. First, from a limited number of measurements using UWB simulators, NTIA found that the received average (RMS) power from two identical UWB emitters is approximately twice that from a single UWB emitter, in agreement with the linear addition assumption. These results logically extend to an arbitrarily large number of UWB emitters. Second, NTIA examined four other aggregate interference methodologies described in the literature and found that all yielded results quite similar (within 2 dB) to those derived from the NTIA UWBRings model for a variety of hypothetical UWB scenarios. The UWBRings model, however, is unique in its ability to effectively consider various modes of radio propagation and three-dimensional receiver antenna patterns, both being key factors for aggregate studies.

Results of these studies show that received aggregate average (RMS) power from a uniform distribution of identical UWB emitters varies directly with the UWB EIRP, UWB emitter density, and number of active transmitters (transmitter activity factor). These results show that under ideal radio propagation conditions, *i.e.*, with no man-made or natural obstructions, aggregate interference levels from UWB devices can exceed that from a single emitter at densities as low as a few emitters per square kilometer or more than 1000 emitters per square kilometer, depending on the specific receiver.

While some studies of aggregate effects filed in response to the FCC's UWB NPRM used a comparable analytic methodology to that used by NTIA, the studies typically compared the aggregate interference levels to that from a single UWB emitter situated at an unrealistically close distance to the receiving antenna. As a result, conclusions from these studies are misleading.

NTIA also examined additional factors that tend to mitigate aggregate interference as an issue, including higher propagation losses associated with irregular terrain, urban and suburban environments, and building penetration, or antenna directivity. A possible methodology is described for applying these factors.

3.3.3 Interpretation of Results

This NTIA study shows that operation of UWB devices is feasible in portions of the spectrum between about 3.1 and 5.650 GHz at heights of about 2 meters with some operating constraints.[15] Operations of UWB devices below 3.1 GHz will be quite challenging and any policy developed will need to consider the results of the analyses of interactions of GPS and UWB systems underway at NTIA and other facilities. RTCA notes that the NTIA analysis shows UWB compatibility problems exist under certain circumstances with FSS earth stations, MLS and Terminal Doppler Weather Radar which all operate between 3.1 and 5.65 GHz.

While the study showed that aggregate UWB interference can be a significant factor to receiving systems under ideal propagation conditions, a number of mitigating factors must also be taken into account that may reduce or eliminate these aggregate affects. There are also numerous mitigating factors that could relax restrictions on operation of UWB devices below 3.1 GHz. Although these are discussed in the report, the development of suitable policy restrictions and guidance for both aggregate and single emitter interference is beyond the scope of this report and must await the results of the ongoing UWB measurement programs, including those of the GPS.

[15] UWB operations at greater heights between 3.1 and 5.650 GHz and near low elevation angle 4 GHz FSS earth stations may have to be constrained with respect to such factors as spectral output power, amount of operating time, and quantity of units operating in any area.

3.4 NTIA GPS RFI Susceptibility Tests and Analysis

The study described in this section was undertaken by the NTIA to assess the electromagnetic compatibility (EMC) of the proposed UWB transmitting devices with GPS receivers. The primary objective of the NTIA study was to define maximum allowable UWB effective isotropic radiated power (EIRP)[16] levels that can be tolerated by GPS receivers, when used within various operational applications, without causing degradation to GPS operations.

3.4.1 Measurement Approach

A two-part approach consisting of both a measurement and an analysis component was adopted for this assessment. NTIA's Institute for Telecommunication Sciences (ITS) measured the interference susceptibility of various GPS receiver architectures to a set of UWB waveforms.[17] Utilizing the measured GPS receiver interference susceptibility levels, analyses were performed by the NTIA Office of Spectrum Management (OSM) for various operational scenarios to determine the maximum allowable UWB EIRP level that can be tolerated by GPS receivers before performance degradation is realized.

3.4.1.1 GPS Receivers Selected for Testing

The NTIA study attempted to measure across the space of GPS receiver architectures. One receiver from each of three basic GPS receiver architectures was identified for inclusion in the measurements. The receiver architectures represented are: C/A-code tracking receivers (which make up a significant share of the civil GPS receivers in use today), semi-codeless receivers (used in low-dynamic applications requiring high precision), and C/A-code tracking receivers employing multiple, narrowly-spaced correlators to enhance accuracy and mitigate the effects of multipath. In addition to these three technologies, a TSO-C129a compliant receiver is to be tested.

3.4.1.2 UWB Signals Examined

NTIA identified 32 UWB signal permutations for examination with respect to their interference potential to GPS receivers. For each of four pulse repetition frequencies (PRFs);100 kHz, 1 MHz, 5 MHz, and 20 MHz, eight distinct UWB waveforms were generated by combining four modulation types (constant PRF, On-Off Keying (OOK), 2% relative dither, and 50% absolute dither) and two states of gating (100% and 20%). For the measurements performed in this study, the gated UWB signal utilized a scheme where a burst of pulses lasting 4 milliseconds (ms) was followed by a 16 ms period when no pulses were transmitted. UWB pulse width of 0.5ns was used for all single-entry measurements. A combination of 0.5 and 0.245 ns pulse widths was used in the aggregate testing. All UWB waveforms were characterized by measured average power in the GPS band. NTIA has stated that the data collected from these measurements are applicable only to the UWB signal permutations that were considered in this assessment, and that no attempt should be made to extrapolate this data beyond these particular UWB parameters.

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[16] The computation of EIRP is in terms of the average power of the UWB signal for all cases considered in this section. This average power is based on root-mean-square (RMS) voltage.

[17] NTIA 01-384

3.4.1.3 Performance Criteria Used

The two performance criteria examined were the "break-lock" and "reacquisition" thresholds. Break-lock threshold refers to the UWB power level causing loss of signal lock between the GPS receiver and a GPS satellite. The reacquisition threshold is defined as the UWB power level that results in an abrupt increase in reacquisition time.

3.4.1.4 Measurements Performed

ITS performed closed system (conducted) measurements to assess the potential impact to each of the GPS receivers from both a single UWB transmitter (single entry) interaction and from a multiple UWB transmitter (aggregate) interaction. To examine the applicability of the conducted measurements, the effects of the GPS antenna on the radiated signals within the frequency band of interest were measured. Measurements were performed wherein the UWB signal was radiated and received within an anechoic chamber to prevent outside interference sources from affecting the results. Amplitude probability distribution (APD) measurements were also performed for each of the UWB signal permutations considered in this effort, to aid in classifying the UWB signals. APD gives a measure of the signal characteristics within the GPS receiver bandwidth.

The data collected from the measurements were used to calculate the maximum allowable EIRP that can be emitted from a UWB transmitter without exceeding the measured interference susceptibility level. A source-path-receiver analysis was performed to calculate these maximum allowable EIRP levels for both a single UWB transmitter-to-GPS receiver interaction and for the case of an aggregate of UWB transmitters-to-GPS receiver interaction. The operational scenarios considered in the NTIA study are discussed in Section 3.4.3 below.

3.4.2 Analysis Approach

The measurements performed by the ITS define the interference threshold of a UWB transmission system as a function of the UWB signal parameters (e.g., power, PRF, gating, modulation). The interference threshold is measured at the input of the GPS receiver and is used in the analysis for each specific GPS/UWB operational scenario to calculate the maximum allowable emission level at the output of the UWB device antenna. The following paragraphs describe the analysis method used.

3.4.2.1 Link Analysis Equation

The maximum allowable emission level from the UWB device is based on an EIRP limit. The EIRP is the power supplied to the antenna of the UWB device multiplied by the relative antenna gain of the UWB device in the direction of the GPS receiver. The maximum allowable EIRP is computed using the following equation:

$$EIRP_{max} = I_T - G_r + L_p - L_{mult} - L_{allot} - L_{man} + L_{AF} + L_{BA} - L_{safety} \qquad (1)$$

where:

$EIRP_{max}$ is the maximum allowable EIRP of the UWB device (dBW or dBW/MHz);
I_T is the interference threshold of the UWB signal at the input of the GPS receiver (dBW or dBW/MHz);

G_r is the gain of the GPS antenna in the direction of the UWB device (dBi);
L_p is the radiowave propagation loss (dB);
L_{mult} is the factor to account for multiple UWB devices (dB);
L_{allot} is the factor for interference allotment (dB);
L_{man} is the factor to account for manufacturer variations in GPS receivers (dB);
L_{AF} is the activity factor of the UWB device (dB);
L_{BA} is the building attenuation loss (dB);
L_{safety} is the aviation safety margin (dB).

The following paragraphs explain each of the technical factors used in the analysis.

3.4.2.2 Link Equation Factors

UWB Interference Threshold (I_T)

The UWB interference threshold referenced to the input of the GPS receiver is obtained from the single source interference susceptibility measurements performed by ITS as discussed in the NTIA OSM Report Section 2.1.1 (Tables 2-1 and 2-2)[18]. Adjustments are made to the measured interference susceptibility levels to compute the UWB interference threshold. As discussed in OSM Report Section 3.3 (Tables 3-13 and 3-14)[19], the adjustments made to the measured interference susceptibility levels are based on the individual UWB signal structure.

GPS Receiver Antenna Gain (G_r)

The GPS antenna gain model used in this analysis is provided in Table 3.3. The antenna gain used is based on the position of the UWB device with respect to the GPS antenna and is determined from the GPS/UWB operational scenario under consideration.

Table 3.3. GPS Antenna Gain Based on UWB Device Position With Respect to GPS Antenna

Off-axis Angle (Measured with Respect to the Horizon)	GPS Antenna Gain (dBi)
-90 degrees to -10 degrees	-4.5
-10 degrees to 10 degrees	0
10 degrees to 90 degrees	3

The off-axis angle measured with respect to the horizon is computed by:

$$\alpha = \tan^{-1} [(h_{UWB} - h_{GPS})/D] \quad (2)$$

where

α is the angle measured with respect to the horizon (degrees);
h_{UWB} is the UWB device antenna height (m);
h_{GPS} is the GPS receiver antenna height (m);

[18] NTIA 01-45, Sec. 2.1.1
[19] NTIA 01-45, Sec 3.3, pp 3-26, -27

D is the horizontal separation between the GPS receiver and UWB device antennas (m).

RTCA notes that this antenna gain model may not be applicable for applications involving ground-plane mounted antennas such as in aviation.

Radiowave Propagation Model (L_p)

The radiowave propagation loss is computed using the minimum distance separation between the GPS receiver and the UWB device as defined by the GPS/UWB operational scenario. The radiowave propagation model used also depends on the GPS/UWB operational scenario. By definition, "free-space" assumes that there is a line-of-sight (LOS) path between the UWB device and the GPS receiver. The radiowave propagation model described by the free-space loss equation is :

$$L_p = 20 \text{ Log } F + 20 \text{ Log } D_{min} - 27.55 \tag{3}$$

where:

L_p is the free-space propagation loss (dB);
F is the frequency (MHz);
D_{min} is the minimum distance separation between the GPS receiver and UWB device (m).

As a result of antenna heights and terrain conditions, free-space conditions may not exist. There is a phenomenon referred to as the propagation loss breakpoint, which consists of a change in the slope of the propagation loss with distance at a radial distance from the transmitter. It is caused by the reflection of the transmitted signal. This multipath signal interferes with the direct path signal and usually occurs only in areas with clear LOS and ground reflection paths.

For the frequency range of interest, the propagation loss changes by 20 dB/decade (i.e., free-space loss) close to the transmitter, and by 40 dB/decade after the propagation loss breakpoint occurs. The propagation loss breakpoint radius from the transmitter, R_b, is calculated using the formula [20]:

$$R_b = 2.3\text{x}10^{-6} F (h_t h_r) \tag{4}$$

where:

R_b is the propagation loss breakpoint radius (mi);
F is the frequency (MHz);
h_t is the UWB device antenna height (ft);
h_r is the GPS receiver antenna height (ft).

When the minimum distance separation between the UWB device and the GPS receiver is less than R_b, the free-space propagation model should be used. When the minimum distance separation between the UWB device and the GPS receiver is greater than R_b, a propagation model that takes into account non-LOS conditions should be used.

Multiple UWB Devices (L_{mult})

The GPS/UWB operational scenario determines whether single or multiple UWB devices should be considered. The factor for multiple UWB devices was obtained from the multiple source

[20] E. N. Singer, *Land Mobile Radio Systems* (Second Edition) at 194.

(aggregate) measurements performed by ITS. OSM Report Section 2.1.2[21] discusses the multiple UWB devices measurement results. Based on the multiple source measurements, the factor to be included in the analysis for multiple UWB devices will depend on whether the interference effect has been characterized as being pulse-like, CW-like, or noise-like. The exception is the en-route navigation operational scenario, where it is assumed that there are a large enough number of UWB devices, such that independent of the individual UWB signal parameters, the aggregate effect causes noise-like interference.

As discussed in OSM Report Section 2.2.3, signals that were characterized as being pulse-like for single UWB device interactions were characterized as being noise-like when multiple UWB devices are considered. The occurrence of the transition from pulse-like to noise-like interference was verified in Measurement Case V[22]. The number of UWB devices required for this transition to occur depends on the PRF. For the 1 MHz PRF signals, the measurements show that three signals are required for the transition to occur. In the case of the 100 kHz PRF signals, the number of UWB devices necessary for the transition to occur will be much larger than the number of UWB devices under consideration in the operational scenarios. Based on the measurement results, a factor for multiple UWB devices is not included in this analysis for signal permutations that have been characterized as causing pulse-like interference with a PRF of 100 kHz.

[The interference effect for UWB signals that have been characterized as being CW-like is attributed by NTIA to the single interfering CW line that is coincident with a dominant C/A code line.] This was discussed in Section [2.2.3], and confirmed in Measurement Cases III and IV. Multiple UWB signals that are characterized as causing CW-like interference, do not add to determine the effective interfering signal power. RTCA notes that this conclusion is based solely on the break-lock threshold measurements. A large number of UWB devices producing spectral lines would be necessary before there is a transition to a noise-like interference effect. This transition from CW-like to noise-like will not occur with the number of UWB devices under consideration in the operational scenarios. Based on the measurement results, a factor for multiple UWB devices is not included in this analysis for UWB signal permutations that have been characterized as causing CW-like interference.

UWB signals permutations with PRFs of 1 MHz, 5 MHz, and 20 MHz that have been characterized as being pulse-like, will transition to noise-like interference as the number of UWB devices is increased. This is discussed in Section [2.2.3] and verified in Measurement Case V. For these UWB signals permutations, a factor of 10 Log (number of UWB devices) is included in the analysis.

As discussed in Section [2.2.3], and verified in Measurement Case I and II, if the individual signals cause an interference effect that is noise-like, the interference effect of the multiple noise-like signals is noise-like. Based on the measurement results, for UWB signal permutations that have been characterized as causing noise-like interference, a factor of 10 Log (number of UWB devices) is included in the analysis.

[21] NTIA 01-45, Sec. 2.1.2, pg. 2-5
[22] NTIA 01-45, Table 2-3, pg. 2-5

Interference Allotment (L_{allot})

Several potential sources of interference to GPS L1 receivers have been identified. These include but are not limited to: 1) adjacent band interference from mobile satellite service (MSS) handsets; 2) harmonics from television transmitters; 3) adjacent band interference from super geostationary (super GEO) satellite transmitters[23]; 4) spurious emissions from 700 MHz public safety base, mobile, and portable transmitters; and 5) spurious emissions including harmonics from 700 MHz commercial base, mobile, and portable transmitters. Multiple sources of interference, which might individually be tolerated by a GPS receiver, may combine to create an aggregate interference level (e.g., noise and emissions) that could prevent the reliable reception of the GPS signal. In the GPS/UWB operational scenario, a percentage of the total allotment for all interfering sources will be attributed specifically to UWB devices.

In this analysis the percentage of the total interference allotment that is attributed to UWB devices is dependent on the minimum distance separation between the GPS receiver and the UWB device. The minimum distance separation is established by each operational scenario. For operational scenarios where the minimum distance separation is small (e.g., on the order of several meters), the UWB device is expected to be the dominant source of interference, and 100% of the total interference is allotted to UWB devices. For operational scenarios where a larger distance separation exists, there is a greater likelihood that other interfering sources will contribute to the total interference level at the GPS receiver. In these operational scenarios, 50% of the total interference is allotted to UWB devices. That is, one half of the total allowable interference is allotted to UWB and the other half is allotted to all other interfering sources combined. For the aviation operational scenarios, larger geographic areas are visible to a GPS receiver onboard an aircraft. This larger field of view will increase the number of interfering sources that can contribute to the total interference level at the receiver. In the aviation operational scenarios, 10% of the total interference is allotted to UWB devices. The factor for UWB device interference allotment is computed from 10 Log(UWB interference allotment ratio). For example, if the UWB device interference allotment is 50% (a ratio of 0.5), a 3 dB factor is included in the analysis.

GPS Receiver Variation (L_{man})

The ITS measurement effort did not consider multiple samples of each model of GPS receiver. Therefore, it is not possible to determine if there is a statistical variation in the performance of GPS receivers. As an estimate, a 3 dB factor has been included to take into account likely variations among GPS receivers of the same model as well as variations in GPS receivers from different manufacturers.

UWB Device Activity Factor (L_{AF})

The activity factor represents the percentage of time that the UWB device is actually transmitting. For example, a UWB device that is transmitting continuously will have an activity factor of 100%, no matter what PRF, modulation, or gating percentage is employed. The activity factor is only applicable when multiple UWB devices are considered in the GPS/UWB operational scenario. Some UWB devices are expected to have inherently low activity factors such as those that are manually activated with a trigger or "deadman" switch. Others will likely

[23] Super GEOs are geostationary earth orbiting satellites that are designed to employ a high transmit power to communicate with mobile handsets.

have high activity factors such as a UWB local area network. Since it was not possible to estimate practical values of activity factors for each potential UWB application, an activity factor of 100% (a ratio of 1) was used in all of the operational scenarios considered in this analysis. Thus, the activity factor used is set equal to 0 dB (i.e., 10 Log (1)).

Building Attenuation (L_{BA})

For GPS/UWB operational scenarios that consider the use of UWB devices operating indoors a building attenuation factor is included. ITS has conducted building attenuation loss measurements at 912, 1920, and 5990 MHz.[24] The measurements were performed for different buildings representing typical residential and high rise office construction. Based on the results of these measurements, whenever the UWB device is considered to be operating indoors an average building attenuation of 9 dB is used.

Aviation Safety Margin (L_{safety})

When the GPS/UWB operational scenario involves aviation applications using GPS (e.g., en-route navigation and non-precision approach landing) a safety margin is appropriate. The aviation safety margin takes into account sources of radio-frequency interference that are real but not quantifiable (e.g., multipath). A safety margin of 6 dB is included for GPS receivers used in aviation applications.[25] RTCA notes that material has been presented indicating that a safety margin is appropriate for non-aviation, safety-related scenarios.

[GPS Receiver Architecture] Use Material

Interference susceptibility measurements were performed on the C/A code and semi-codeless GPS receiver architectures. The GPS receiver architecture examined in the analysis are different depending upon the operational scenario under consideration. In those where the GPS receivers are used in moving [vehicles] (terrestrial, maritime, and railway), the C/A code architecture was used. In the surveying operational scenario, where the GPS receiver is not moving (or moving very slowly), the semi-codeless receiver architecture was used. For the en-route navigation and non-precision approach landing operational scenarios, a TSO-C129a compliant GPS receiver will be used.[26]

3.4.3 Development of the GPS/UWB Operational Scenarios

As discussed in the previous section, the measurements of the maximum tolerable interference threshold at the input to the GPS receiver is used in this analysis to compute the maximum allowable EIRP of the UWB device. The operational scenario is necessary to relate the interference level at the input of the GPS receiver to the output of the UWB device. The GPS/UWB operational scenarios establish: the minimum distance separation between the GPS receiver and the UWB device; the appropriate antenna coupling; the applicable radio wave

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[24] National Telecommunications and Information Administration, Institute for Telecommunication Sciences, NTIA Report 95-325, Building Penetration Measurements From Low-height Base Stations at 912, 1920, and 5990 MHz, at 43.

[25] ITU-R M.1477 at Annex 5.

[26] The measurement results of the C/A code TSO-C129a receiver are not available at this time. The analysis results that are presented are based on the measurements for the non-aviation C/A code receiver. Although not aviation certified, it is representative of the architecture used by aviation in these applications. When data on the TSO-C-129a receiver is available, the results of the analysis may be revised.

propagation model; whether single or multiple UWB devices should be considered; and any other scenario specific factors (e.g., building attenuation and aviation safety margin).

Five categories of GPS applications are considered in the development of the GPS/UWB operational scenarios: terrestrial, maritime, railway, surveying, and aviation (en route and nonprecision approach). The operational scenario proposals also considered several UWB device applications. The UWB device applications include: embedded functions in a mobile phone, wireless local area networks, and short-range communication systems. The specific operational scenarios included GPS receivers used in the following applications[27]:

- Public Safety (E-911 embedded in a cellular phone);
- Public Safety (emergency response vehicles);
- Geographic Information Systems;
- Precision Machine Control;
- Maritime (constricted waterway navigation, harbor navigation, docking and lock operations;)
- Railway (positive train control);
- Surveying;
- Aviation (en-route navigation and non-precision approach landings).

In addition to these specific GPS/UWB operational scenarios, NTIA proposed a general operational scenario for GPS receivers used for terrestrial applications that considered multiple UWB device interactions. None of the scenarios investigated considered devices containing both UWB and GPS. Also, UWB and GPS both operating indoors was not considered by NTIA, but is discussed elsewhere in this report.[28]

3.4.4 NTIA Measurement and Analysis Results

3.4.3.1 Measurement Results Discussion

The single entry measurement results indicate that both the C/A-code tracking GPS receiver and the semi-codeless GPS receiver demonstrate a degree of tolerance to all of the UWB 100 kHz PRF signal permutations examined. For the thirteen scenarios considered in this assessment, aggregate effects were deemed by NTIA not to be a concern with respect to those UWB waveforms with a PRF of 100 kHz. {RTCA notes that above a certain UWB device density for the enroute aviation scenario even 100 kHz PRF UWB emitters can cause noise-like interference at an unacceptable level when operating at Part 15 limits. [Ed. note: Fig. 3-37, 3-38 are both for indoor UWB devices. The calculation in the report appendix apparently used proper factors]. RTCA also notes the en route scenario only considered off-aircraft ground sources with a minimum separation distance of 1,000 feet, and did not consider potential on-board RFI sources.} When the PRF was increased to 1 MHz, the C/A-code receiver began to show continuous wave (CW)-like interference susceptibility to the unmodulated UWB signal permutations at low power levels. When the PRF was increased to 5 MHz and then to 20 MHz, CW-like interference effects to the C/A-code receiver were observed to be more prevalent.

[27] All of the documents from the public meetings are available upon request from the NTIA Office of Spectrum Management or from the NTIA website.

[28] RTCA Second Interim Report, Section 4.3.1

The measurements also show that dithering of the UWB pulses in the time domain, using the techniques considered in the NTIA assessment, can be effective in spreading the spectral lines in the frequency domain, making the effect of the signal appear more noise-like. {RTCA notes that the effectiveness of spectral line-spreading is quite complex[[29]].} The GPS C/A-code receiver showed approximately 10 dB less susceptibility to these noise-like UWB signals as compared to those UWB signals deemed to have a CW-like effect. For PRFs of 1 MHz, 5 MHz, and 20 MHz, some of the UWB waveforms caused an effect similar to low duty cycle pulsed interference, to which the GPS C/A-code receiver is relatively tolerant. However, the multiple-entry (aggregate) measurements indicate that this advantage is lost when a multiple of as few as three of these UWB signals with equivalent power levels at the GPS receiver input are considered in aggregation. The aggregate measurements also verify that when multiple noise-like UWB signals are considered with equivalent power levels at the GPS receiver input, the effective aggregate signal level in the receiver intermediate frequency (IF) bandwidth is determined by adding the average power of each of the UWB signals.

For all of the UWB signal permutations employing PRFs of 1, 5, and 20 MHz, the semi-codeless GPS receiver measured in the NTIA assessment showed susceptibility similar to what was measured in the broadband noise interference baseline. RTCA notes that this is because the semi-codeless technique spreads the interference using the P-code, rather than the C/A code. The semi-codeless GPS receiver was more susceptible than the C/A-code receiver to noise-like interference.

3.4.3.2 Analysis Results

In the analysis component of the study, NTIA determined the maximum allowable EIRP level for the different UWB signal permutations using the operational scenarios. The results of the analysis are summarized in Tables 3.4 through 3.7.[30] Each table corresponds to a UWB PRF examined in the analysis. Tables 3.4 through 3.7 also include a comparison of the computed maximum allowable EIRP level with the current Part 15 level of -71.3 dBW/MHz. When the interference effects are classified as pulse-like or noise-like, the maximum allowable EIRP spectral density can be directly compared to the current Part 15 level. When the interference effect is classified as CW-like, the maximum allowable EIRP level can be directly compared to the Part 15 level, only if it is assumed that there is a single spectral line in the measurement bandwidth. As shown in Tables 3.4 through 3.7, the results of the analysis indicates that the maximum allowable EIRP necessary to satisfy the measured performance thresholds of the GPS receivers considered in this study is very dependent on the UWB signal structure.

3.4.5 NTIA Conclusions

The following general conclusions were drawn by NTIA based on the findings of the study:[31]

1) The GPS receiver performance thresholds measured within this study are consistent with the interference protection limits developed within national and international GPS study groups.

[29] See NTIA report 01-384, Appendix C, page C-3.
[30] NTIA 01-45 at Executive Summary
[31] NTIA 01-45 at pg. 4-27.

2) When multiple noise-like UWB signals with equivalent power levels at the GPS receiver input are considered, the effective aggregate signal level in the receiver IF bandwidth is determined by adding the average power of each of the UWB signals.

3) Within the limitations of this study (i.e., the available number of UWB signal generators), it was found that when multiple CW-like UWB signals are considered, the effective aggregate interference effect to a C/A-code GPS receiver is the same as that of a single CW-like signal. The interference mechanism is a result of the alignment of a UWB spectral line with a GPS C/A-code line. [ref. Previous RTCA comment]

4) The CW-like interference effect is not applicable to the semi-codeless receiver examined when operating in the dual frequency mode. RTCA notes that this finding is not consistent with the need for C/A tracking to aid the P(Y) tracking, and that further examination is desired.

5) A GPS antenna does not offer any additional attenuation to that portion of a UWB signal within the GPS frequency band.

6) For those UWB signals examined with a PRF of 100 kHz, maximum permissible EIRP levels between -73.2 and -26.5 dBW/MHz are necessary to ensure EMC with the GPS applications defined by the operational scenarios considered within this study. [ref. Previous RTCA comment].

7) For those UWB signals examined with a PRF of 1 MHz, the maximum allowable EIRP levels necessary to achieve EMC with the GPS receiver applications considered in this study range from -70.2 to -104.3 dBW for the CW-like (unmodulated) UWB waveforms, and -57.6 to -91.6 dBW/MHz for the noise-like (modulated and/or dithered) UWB waveforms.

8) For those UWB signals examined with a PRF of 5 MHz, the maximum allowable EIRP levels necessary to ensure EMC with the GPS receiver applications considered in this study range from -70.7 to -106.1 dBW for the CW-like (non-dithered) UWB waveforms, and from -49.6 to -97.6 dBW/MHz for the noise-like (dithered) UWB waveforms.

9) For those UWB signals examined with a PRF of 20 MHz, the maximum allowable EIRP levels required to ensure EMC with all of the GPS receiver applications considered in this study range from -71.0 to -106.9 dBW for the CW-like (non-dithered) UWB waveforms, and from -60.0 to -98.6 dBW/MHz for the noise-like (dithered) UWB waveforms.

Table 3.4. Summary of Analysis Results (PRF = 100 kHz)

Operational Scenario Description					UWB Signal Characteristics			GPS Receiver Architecture	Classification of Interfering Signal	Maximum Interference Threshold (dBW/MHz)	Maximum Allowable EIRP (dBW/MHz)	Comparison with the Current Part 15 Level (dB)
GPS Application	UWB Single	UWB Multiple	UWB Indoor	UWB Outdoor	PRF (MHz)	Gating %	Mod.					
Terrestrial	X			X	0.1	100	None	C/A-code	Pulse-Like	-112.6	-73.2	1.9
Terrestrial		X	X		0.1	100	None	C/A-code	Pulse-Like	-112.6	-57.6	-13.7
Terrestrial		X		X	0.1	100	None	C/A-code	Pulse-Like	-112.6	-62.3	-9
Maritime			X		0.1	100	None	C/A-code	Pulse-Like	-112.6	-41.7	-29.6
Maritime		X		X	0.1	100	None	C/A-code	Pulse-Like	-112.6	-48.1	-23.2
Railway		X	X		0.1	100	None	C/A-code	Pulse-Like	-112.6	-56.3	-15
Railway		X		X	0.1	100	None	C/A-code	Pulse-Like	-112.6	-57.8	-13.5
Surveying	X			X	0.1	20	2% Rel.	Semi-Codeless	Noise-Like	-138	-81.1	9.8
Surveying		X		X	0.1	20	2% Rel.	Semi-Codeless	Noise-Like	-138	-81.2	9.9
Aviation-NPA		X		X	0.1	100	None	C/A-code	Pulse-Like	-112.6	-52.9	-18.4
Aviation-ER		X	X		Note 1	Note 1	Note 1	C/A-code	Noise-Like	-134.8	-76.6[2]	5.3
Aviation-ER		X		X	Note 1	Note 1	Note 1	C/A-code	Noise-Like	-134.8	-85.6[2]	14.3

Notes: En-Route Navigation (ER), Non-Precision Approach (NPA)
1. In this operational scenario, it is assumed that there is a large enough number of UWB devices such that independent of the individual UWB signal parameters, the aggregate effect causes noise-like interference.
2. This maximum allowable EIRP is based on an assumed density of 200 UWB devices per square kilometer transmitting simultaneously .

Table 3.5. Summary of Analysis Results (PRF = 1 MHz)

Operational Scenario Description					UWB Signal Characteristics							
GPS Application	UWB Single	UWB Multiple	UWB Indoor	UWB Outdoor	PRF (MHz)	Gating %	Mod.	GPS Receiver Architecture	Classification of Interfering Signal	Maximum Interference Threshold[1]	Maximum Allowable EIRP[1]	Comparison with the Current Part 15 Level (dB)
Terrestrial	X			X	1	100	None	C/A-code	CW-Like	-143.7	-104.3	33
Terrestrial	X			X	1	100	2% Rel.	C/A-code	Pulse-Like	-131	-91.6	20.3
Terrestrial		X	X		1	100	None	C/A-code	CW-Like	-143.7	-88.7	17.4
Terrestrial		X	X		1	20 & 100	Multiple	C/A-code	Noise-Like	-134.5	-85.5	14.2
Terrestrial		X		X	1	100	None	C/A-code	CW-Like	-143.7	-93.4	22.1
Terrestrial		X		X	1	20 & 100	Multiple	C/A-code	Noise-Like	-134.5	-90.2	18.9
Maritime		X	X		1	100	None	C/A-code	CW-Like	-143.7	-72.8	1.5
Maritime		X	X		1	20 & 100	Multiple	C/A-code	Noise-Like	-134.5	-69.6	-1.7
Maritime		X		X	1	100	None	C/A-code	CW-Like	-143.7	-79.2	7.9
Maritime		X		X	1	20 & 100	Multiple	C/A-code	Noise-Like	-134.5	-76	4.7
Railway		X	X		1	100	None	C/A-code	CW-Like	-143.7	-87.4	16.1
Railway		X	X		1	20 & 100	Multiple	C/A-code	Noise-Like	-134.5	-83.0	11.7
Railway		X		X	1	100	None	C/A-code	CW-Like	-143.7	-88.9	17.6
Railway		X		X	1	20 & 100	Multiple	C/A-code	Noise-Like	-134.5	-84.5	13.2
Surveying	X			X	1	100	50% Abs.	Semi-Codeless	Noise-Like	-151	-94.1	22.8
Surveying		X		X	1	100	50% Abs.	Semi-Codeless	Noise-Like	-151	-94.2	22.9
Aviation-NPA		X		X	1	100	None	C/A-code	CW-Like	-143.7	-84	12.7
Aviation-NPA		X		X	1	20 & 100	Multiple	C/A-code	Noise-Like	-134.5	-80.8	9.5
Aviation-ER		X	X		Note 2	Note 2	Note 2	C/A-code	Noise-Like	-134.8	-76.6[3]	5.3
Aviation-ER		X		X	Note 2	Note 2	Note 2	C/A-code	Noise-Like	-134.8	-85.6[3]	14.3

Notes: En-Route Navigation (ER), Non-Precision Approach (NPA)
1. When the interference effect has been classified as pulse-like or noise-like, the value is expressed in units of dBW/MHz. The value is expressed in units of dBW when the interference effect has been classified as CW-like.
2. In this operational scenario, it is assumed that there is a large enough number of UWB devices, such that independent of the individual UWB signal parameters the aggregate effect causes noise-like interference.
3. This maximum allowable EIRP is based on an assumed density of 200 UWB devices per square kilometer transmitting simultaneously.

Table 3.6. Summary of Analysis Results (PRF = 5 MHz)

Operational Scenario Description					UWB Signal Characteristics							
GPS Application	UWB Single	UWB Multiple	UWB Indoor	UWB Outdoor	PRF (MHz)	Gating %	Mod.	GPS Receiver Architecture	Classification of Interfering Signal	Maximum Interference Threshold[1]	Maximum Allowable EIRP[1]	Comparison with the Current Part 15 Level (dB)
Terrestrial	X			X	5	100	None	C/A-code	CW-Like	-145.5	-106.1	34.8
Terrestrial	X			X	5	20	50% Abs.	C/A-code	Pulse-Like	-105	-65.6	-5.7
Terrestrial	X			X	5	100	50% Abs.	C/A-code	Noise-Like	-137	-97.6	26.3
Terrestrial		X	X		5	100	None	C/A-code	CW-Like	-145.5	-90.5	19.2
Terrestrial		X	X		5	100	50% Abs.	C/A-code	Noise-Like	-137	-88	16.7
Terrestrial		X		X	5	100	None	C/A-code	CW-Like	-145.5	-95.2	23.9
Terrestrial		X		X	5	100	50% Abs.	C/A-code	Noise-Like	-137	-92.7	21.4
Maritime		X	X		5	100	None	C/A-code	CW-Like	-145.5	-74.6	3.3
Maritime		X	X		5	100	50% Abs.	C/A-code	Noise-Like	-137	-72.1	0.8
Maritime		X		X	5	100	None	C/A-code	CW-Like	-145.5	-81	9.7
Maritime		X		X	5	100	50% Abs.	C/A-code	Noise-Like	-137	-78.5	7.2
Railway		X	X		5	100	None	C/A-code	CW-Like	-145.5	-89.2	17.9
Railway		X	X		5	100	50% Abs.	C/A-code	Noise-Like	-137	-85.5	14.2
Railway		X		X	5	100	None	C/A-code	CW-Like	-145.5	-90.7	19.4
Railway		X		X	5	100	50% Abs.	C/A-code	Noise-Like	-137	-87.0	15.7
Surveying	X			X	5	20 & 100	50% Abs.	Semi-Codeless	Noise-Like	-151	-94.1	22.8
Surveying		X		X	5	20 & 100	50% Abs.	Semi-Codeless	Noise-Like	-151	-94.2	22.9
Aviation-NPA		X		X	5	100	None	C/A-code	CW-Like	-145.5	-85.8	14.5
Aviation-NPA		X		X	5	100	50% Abs.	C/A-code	Noise-Like	-137	-83.3	12
Aviation-ER		X	X		Note 2	Note 2	Note 2	C/A-code	Noise-Like	-134.8	-76.6[3]	5.3
Aviation-ER		X		X	Note 2	Note 2	Note 2	C/A-code	Noise-Like	-134.8	-85.6[3]	14.3

Notes: En-Route Navigation (ER), Non-Precision Approach (NPA)

1. When the interference effect has been classified as pulse-like or noise-like, the value is expressed in units of dBW/MHz. The value is expressed in units of dBW when the interference effect has been classified as CW-like.
2. In this operational scenario, it is assumed that there is a large enough number of UWB devices, such that independent of the individual UWB signal parameters the aggregate effect causes noise-like interference.
3. This maximum allowable EIRP is based on an assumed density of 200 UWB devices per square kilometer transmitting simultaneously.